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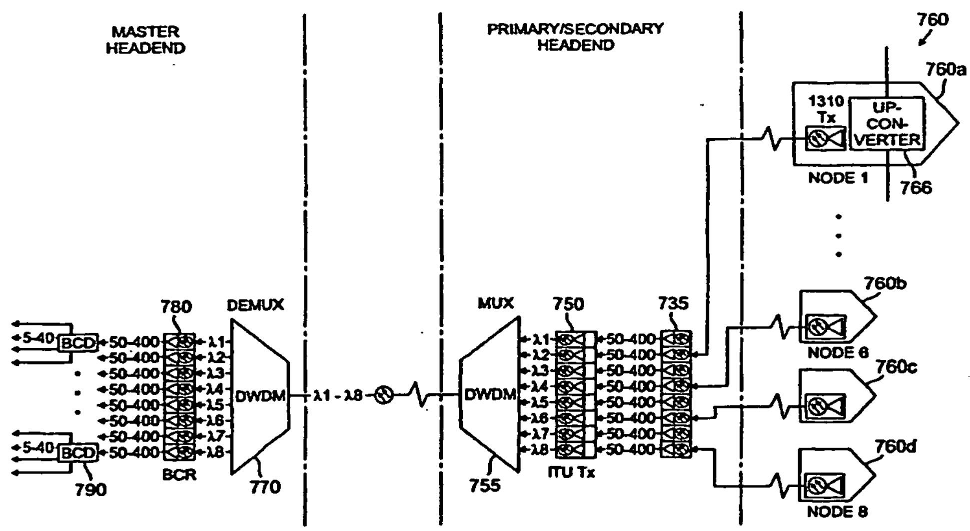

DWDM/FSS CONFIGURATION 1

(57) Abstract

A bidirectional dense wave division multiplexing (DWDM) cable television network architecture with frequency stacking system provides increased capacity in the reverse path. The combination of optical multiplexing, using dense wave division multiplexing, and RF multiplexing, using frequency stacking, significantly increases the efficiency of the return path in a bidirectional architecture. The ITU grid transmitters and the frequency stacking system may be located at the nodes, at the primary or secondary headends, or with the frequency stacking system at the node and the ITU grid transmitters at the primary/secondary headend.

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Increased Capacity Bidirectional DWDM Network Architecture With Frequency Stacking System

FIELD OF THE INVENTION

The present invention relates generally to a cable television hybrid-fiber-coax (CATV HFC) architecture that provides increased capacity in the reverse path of the network. More particularly, it describes an architecture that incorporates multiplexing, both optical multiplexing, using dense wave division multiplexing (DWDM), and RF multiplexing, using frequency stacking, so as to increase the efficiency of the return path.

BACKGROUND OF THE INVENTION

The evolution of the traditional CATV HFC network into a two-way interactive data communications platform (including cable modems and IP telephony over cable), together with the move toward headend consolidation, has led to a need for more bandwidth in both the forward and reverse paths.

Specifically, in a typical CATV plant today, downstream content occupies the 50-870 MHz frequency partition of the network. The return path signals are relegated to the 5-42 MHz frequencies (of course those skilled in the art will appreciate that although the typical reverse path frequency band in the United States is 5-42 MHz, overseas the range varies and may be 5-85 MHz – the concepts discussed herein are not to be interpreted as being limited to the current US range). Given the asymmetrical nature of the frequency bands used it is very likely that the reverse path traffic will be the first to be constrained.

DWDM systems have been deployed to provide segmentation and increased bandwidth. However, by itself, DWDM can add impairment that was not present in the system earlier. In addition, multiplexing in the RF domain using frequency stacking has been used in the reverse path passband to increase bandwidth efficiency. That is, the implementation of a frequency stacking system expands the return bandwidth per home passes and allows for larger node sizes, thereby reducing the overall system costs. Again, however, by itself frequency stacking can add impairment to the system.

The present invention is therefore directed to the problem of developing an architecture that meets the current needs of multiplexed analog and digital systems, segments the forward signal to address individual subscribers and increases bi-directional capacity without the use of additional fiber.

SUMMARY OF THE INVENTION

The present invention provides a hybrid DWDM with frequency stacking architecture that solves the current needs of muliplexed analog and digital systems to provide maximum capacity based on two-way interactive data communications.

According to one embodiment of the present invention, a CATV architecture provides increased capacity in the reverse path network for two-way cable communication and includes a plurality of optical-to-electrical conversion nodes, a primary/secondary headend, and a master headend. The primary/secondary headend interconnects the optical-to-electrical conversion nodes and master headend. The nodes and primary/secondary headend together includes an upconverter for receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands, a plurality of DWDM transmitters, each transmitter having an output on the ITU grid and transmitting a concentration of discrete passbands and a DWDM multiplexer, receiving a signal from each of the plurality of DWDM transmitters and optically multiplexing the DWDM transmitters on a single fiber, the multiplexed signals being routed to the master headend. The master headend includes a DWDM demultiplexer for demultiplexing the received signals from the DWDM multiplexer into individual wavelengths, a plurality of block conversion receivers (BCRs) for receiving the individual wavelengths and converting the signals into composite RF signals and a plurality of block downconverters (BCDs) for receiving the composite RF signals from the BCRs and converting the signals into individual RF signals. The individual RF signals output from the plurality of BCDs correspond to the plurality of coax legs at each optical-to-electrical conversion node.

Another aspect of the invention incorporates an optical amplifier, at the primary/secondary headend, that amplifies the multiplexed signals output from the DWDM multiplexer before being routed to the master headend. In a particular embodiment, the optical amplifier may be an erbium-doped fiber amplifier (EDFA).

Still yet another aspect of the invention includes using Code-Division-Multiple-Access (CDMA), Frequency-Division-Multiple-Access (FDMA), Time-Division-Multiple-Access (TDMA), or any combination thereof, to allow the transport link's available capacity, defined by channel parameters, to be achieved.

Another embodiment of the invention is directed to a method for increasing capacity in the reverse path of a two-way cable communication architecture, the architecture having a plurality of optical-to-electrical conversion nodes, a master headend, and a primary/secondary headend interconnecting the nodes and the master headend. The steps of the method are as follows: receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands, transmitting a concentration of discrete passbands using a plurality of DWDM transmitters, each transmitter having an output on the ITU grid, optically multiplexing the signals received from the DWDM transmitters, using a DWDM multiplexer, on a single fiber, routing the multiplexed signals to the master headend, demultiplexing the received signals into individual wavelengths, receiving the individual wavelengths and converting the signals into composite RF signals and receiving the composite RF signals and converting the signals into individual RF signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other objects, features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 depicts a typical tree-and-branch configuration of a hybrid Fiber/Coax (HFC) cable TV network architecture;

FIG 2 depicts a DWDM subcarrier multiplexed network architecture;

FIG 3 depicts a typical architecture for a DWDM overlay of a standard CATV distribution system;

FIG 4 depicts a block diagram of a typical node configuration;

FIG 5 depicts a typical frequency stacking system (FSS) block diagram;

FIG 6 depicts a fist embodiment of an architecture according to the present invention combining DWDM and FSS technologies;

FIG 7 depicts a first embodiment of an architecture according to the present invention combining DWDM and FSS technologies;

FIG 8 depicts a second embodiment of an architecture according to the present invention combining DWDM and FSS technologies;

FIG 9 depicts a third embodiment of an architecture according to the present invention combining DWDM and FSS technologies;

FIG 10 depicts a composite RF spectrum of four upconverted return-path frequency blocks; and

FIG 11 depicts the bandwidth expansion provided by a combined frequency stacking and DWDM return path system.

DETAILED DESCRIPTION

Typical CATV systems were almost exclusively designed for "one-way transmission" from a headend to the home. Return path implementations were typically lightly loaded and used primarily for low-speed communications with terminals or set top boxes. The recent use of DWDM in CATV was motivated by the need to significantly increase the bi-directional capacity as well as transmission access speed without adding additional fiber

The present invention is directed to a hybrid DWDM/FSS CATV architecture that provides increased capacity in the reverse path network. Consequently, the present invention has significantly improved the ability to handle two-way interactive multimedia communications in existing CATV systems while eliminating the need for the use of additional fiber.

The descriptions of the specific embodiments of the invention follow the brief discussion of DWDM and frequency stacking systems below.

I. DWDM

DWDM systems in CATV today are used exclusively in the 1550 nm optical window (this wavelength window is attractive primarily due to the low fiber loss, approximately 0.22 dB/km at the 1550-nm wavelength, and the use of erbium doped fiber amplifiers (EDFA) to take advantage of the low loss). The wavelengths that comprise the ITU grid are actually a set of predefined frequencies, such as the set

spaced at 100 GHz, from which wavelengths can be derived. The wavelength spacing is approximately 0.8 nm, and the range of wavelengths covers the EDFA band, from about 1530 to 1570 nm. Of course, not all the wavelengths need to be used in any given system and commercial products are available at 100, 200, and 400 GHz spacings, with a variety of individual product offerings. In a preferred embodiment of the invention to be discussed in detail below, the spacing chosen is 200 GHz, and it is this closeness of wavelengths that make the system "dense" (this is to distinguish the DWDM systems from some existing CATV systems which use a combination of 1310 nm and 1550 nm wavelengths in a WDM arrangement). In CATV jargon, the RF signals transmitted over the single-mode fiber (SMF) cables using, for example, DWDM transmitters (such as transmitter 320 in Figure 3 described below), are digital (but of course could also be analog or a combination of digital and analog) using, for example, QAM modulation. The QAM channels are subcarrier multiplexed onto a particular optical wavelength (the terms QAM, digital, targeted services, or DWDM signals are frequently used interchangeably).

Generally, Figure 1 shows a conventional hybrid fiber/coax (HFC) cable TV network architecture. As shown, the signals from the master headend 10 are connected via a "main" or "primary" fiber ring to primary/secondary headends (12a, 12b, 12c) or the secondary "hubs" in a large metropolitan area (14a, 14b, 14c and 14d). The signals are transmitted over single-mode fiber (SMF) using, for example, 1550-nm externally modulated (EM) DFB laser transmitters. The composite signal may be, for example, a mixture of traditional broadcast analog signals with MPEG compressed digital video. At the primary and secondary headends, which may house Synchronous Optical Network (SONET) equipment as well as Cable Modem Termination Systems (CMTSs), routers, and servers for high-speed data, the optical signals may be converted to RF signals and then back to optical signals for transmission to various fiber nodes (16a, 16b, 16c and 16d) using, for example, 1310-nm DFB laser transmitters.

The coaxial portion of the network architecture illustrated in Figure 1, consists of, for example, RF amplifiers, taps, and coaxial cables, and spans from each fiber node (16a-d) to the corresponding subscriber's home(s), where the digital set-top box is placed.

Figure 2 provides an exemplary illustration of a DWDM Subcarrier-Multiplexed (SCM) network architecture for multiple AM/QAM channel transport. In this network architecture, the master cable-TV headend 10 is connected via a main fiber ring to the primary headends (12a, 12b, 12c) in a large metropolitan area. The analog and digital video programs at the master headend 10 are typically received via satellite and terrestrial broadcast as well as via local video servers (those skilled in the art will appreciate that the analog signals could also be "injected" or received at the primary or secondary headends). Ultra-high video trunking capacity is achieved by using high-density wavelength-division-multiplexing (DWDM) and demultiplexing with cascaded Erbium-Doped-Fiber-Amplifiers (EDFA's) (23a, 23b, 23c). In the primary fiber ring, multiple wavelengths in the 1550-nm band, transmitted with each wavelength a mixture of AM and digital video signals, are subcarrier multiplexed (SCM) at either passband traffic, using 64/256-QAM, or even at baseband traffic, such as OC-48. The secondary fiber rings connect the various primary headends to the secondary headends. In a secondary fiber ring, only a few wavelengths are being demultiplexed and transmitted using 1550-nm or 1310-nm laser transmitters with cascaded EDFA's. At the secondary headends, the 1550-nm based broadcast traffic can be switched to a 1310-nm based traffic for both narrowcasting and broadcasting services. In each fiber node, the optical signals transmitted downstream at different wavelengths are converted back to electrical signals using optical receivers, and are transmitted to each subscriber via the coaxial cable plant.

In order to address the return path, Figure 3 shows a simplified master headend 300 (corresponding to reference number 10 of Figures 1 and 2) – primary/secondary headends/hubs 330 (corresponding to reference numbers 12a, 12b, 12c and 14a, 14b, 14c and 14d, respectively, of Figures 1 and 2) -- and node 360 (corresponding to node reference numbers 16a-16d of Figures 1 and 2). This figure is a generic architecture for a DWDM overlay of a conventional hybrid fiber/coax (HFC) cable TV network (note that for exemplary reasons only, Figure 3 assumes that the optical network remains in the 1550nm window from the master headend to the node), and includes an externally-modulated analog transmitter source 305 and a externally modulated DWDM transmitter 320 (of course, this does not have to be a DWDM externally modulated transmitter but may be a directly modulated transmitter). As shown in Figure 3, the

master headend is collectively 300, the primary/secondary headends/hubs are collectively 330, and the nodes collectively 360 (individually 360a, 360b etc.) (those skilled in the art will appreciate that although illustrated as such, the ITU transmitter does not necessarily need to be co-located with the broadcast transmitter).

The DWDM transmitter 320, illustrated as being located at the master headend, includes laser modules for providing the bias, temperature, pre-distortion circuitry and monitoring controls as well as the means of modulating the sources with the RF content. That RF content is either the analog broadcast television signals or the targeted services QAM signal. The modulation techniques are either external (using the modified balanced-bridge Mach-Zehnder interferometer) or direct (using the driving current control of the laser directly).

The output of analog transmitter source 305 is optically amplified 307 to a saturated level (for example, approximately +17 dBm), transmitted through 40 km of standard (non-dispersion shifted) single-mode fiber (SMF) (again, the length of the SMF is provided solely as an exemplary value) to the primary/secondary headend, amplified again by an erbium doped fiber amplifier (EDFA) 335 and split by optical splitter 340 into a number of outputs that matches the number of targeted-services wavelengths.

After splitting, the analog signal is multiplexed with the QAM wavelengths in an analog/digital coupler 350 and that composite signal is again split to serve a number of nodes 360 for which the given wavelength is targeted. In this generic system, nodes 360 are “20 km” away from the primary/secondary headend and are connected using standard SMF (note that there may be multiple nodes targeted per wavelength, especially in the early deployment stages when subscriber take rates are low corresponding to a low bandwidth requirement per node).

Returning to Figure 3, it should be appreciated that the DWDM laser sources are also externally modulated transmitters 320 in the example system, but directly modulated sources may also be used. Eight wavelengths are shown in the figure and are combined into a single fiber in a multiplexer 325 (with 200 GHz spacing, 8 wavelengths may be multiplexed). The multiplexer 325 (and demultiplexer 355 described below) components are used to combine the various ITU grid wavelengths through a low loss coupler and carry them on a single fiber (and demultiplexer 355

subsequently separates those wavelengths to place them onto individual fibers). While the SMF may of course be any length, the standard SMF is 40 km long, and may be distinct from the fiber carrying the analog signal, but may be in the same optical fiber cable bundle (each optical fiber cable bundle consisting of multiple optical fibers). After the 40-km, at the primary/secondary headend location, the combined wavelengths are amplified by EDFA 357 and are then demultiplexed 355 into separate fibers. As noted above, each targeted services wavelength is combined with one of the split analog signal outputs and distributed to nodes 360 through a single fiber carrying both the analog and digital signal. The fiber node 360 contains a receiver that detects both the analog and QAM signals for distribution through the RF plant beyond the node.

In keeping with the drive towards a more symmetric network, the return path illustrated in the DWDM overlay system of Figure 3 mirrors that of the downstream path. One exception to this mirroring occurs not so much in the single fiber of the DWDM system, but in the portion of the return from the node 360 to primary/secondary headend 330. The return path is managed as a two-hop process. In the illustrated system, a temperature compensated 1310/1550 nm laser (typically a DFB) is in the node 360. The time and frequency division multiplexed RF signals from each home served by this node (e.g., 1000-1200 subscribers) drive the DWDM laser 385. The optical output is sent over the link (illustrated as "20 km"), to the primary/ secondary headend 330, where it is detected and amplified by a return receiver 380 before directly modulating an ITU grid DWDM laser transmitter 385. The laser 385 is one of several which combine the entire return path into a DWDM set for transmission over the 40 km back to the master headend 300 and for subsequent processing. Each of the DWDM wavelengths may handle the return traffic from multiple nodes 360 using a combination of time, frequency, or code division multiplexing.

As noted above, the network solution shown in Figure 3 assumes that the optical network remains in the 1550nm window from the master headend to the node. If however an existing system utilizes a re-transmission scheme at the primary/secondary headend, there remains the goal to preserve as much of this infrastructure as possible. Fortunately DWDM can still be used to provide the narrowcast overlay.

II. Frequency Stacking

In frequency stacking systems the 5-42 MHz return passband is block upconverted or shifted to another frequency passband. This may be done in a primary/secondary headend environment or, as we will also discuss herein, in the field located node. The main advantage of the implementation of a frequency stacking system (FSS) is the expansion of the return bandwidth per home passed, which allows for larger node sizes, which in turn reduces the overall system costs (more specifically implementation of FSS provides an expansion in which the same number of users can use a higher speed, or, the system can have a greater number of users).

If we look at "typical" node configuration, shown in Figure 4, all the users served by the node share the return path spectrum. If this were a 1200 home passed node, each home passed would have approximately 29 KHz of guaranteed simultaneous bandwidth (this assumes that the entire 35 MHz is available, and we can dynamically allocate the bandwidth). As Figure 4 illustrates, each of the coaxial busses, RF Leg #1, RF Leg #2, etc., are RF combined into one stream.

Adding more transmitters combined with segmenting the RF paths within the node may increase bandwidth. However, this approach has disadvantages. Beyond adding one additional return transmitter in the node, which only doubles capacity, fiber availability issues may become the limiting factor. To achieve the same level of bandwidth per home passed as FSS three additional transmitters and fibers would be required.

An FSS approach utilizes upconversion in the node to create four passbands for the return. In this approach each leg now has its own 35 MHz of space. The four passbands are RF stacked and sent to the return laser. Figures 5 and 6 illustrate this arrangement.

As Figures 5 and 6 illustrate, there are four major components associated with a FSS system – an upconverter, a transmitter, a receiver and a downcoverter. These components would be common in function regardless of whether the application is hub or node based. Each of these components is briefly discussed below.

Frequency stacking begins with the upconverter 500. This device, simply put, takes multiple return passbands and shifts them to other independent passbands in the spectrum while maintaining the information that resides in the original passband. In the

implementation shown in Figures 5 and 6, each of the RF legs is upconverted to different passbands within the 50–400 MHz passband. A pilot carrier serves two key functions - first, it compensates for the range of link loss introduced by the optical network, and second, it is used by the downconverter to phaselock to the upconverter thus eliminating frequency offsets.

The transmitter used in this application is not a standard, band-limited, return path transmitter. In this implementation, a forward path transmitter 510, designed to operate in the 50-400 MHz passband, is used to transport the upconverted signal from upconverter 500.

The FSS receiver (BCR) 520 is also different than the normal return path receiver (RPR 410 of Figure 4). Again chosen for the forward path, the receiver 520 provides the composite RF output. Contained within this passband are the four upconverted bands along with the pilot carrier. To recover the individual bands, a downconversion process is performed by downcoverter 530, which provides the means of returning the upconverted bands to their original 5-42 MHz spectrum. Using the pilot carrier for frequency synchronization, the block downconverter (BCD) 530 reverses the process initiated in the node and provides four independent 5-42 MHz passbands, one for each of the upconverted bands. These outputs are then fed to the return splitting/combining network and eventually end at the individual service demodulators.

III. Combined DWDM and Frequency Stacking Systems

With the above descriptions of DWDM and FSS systems, Figures 7-9 illustrate, respectively, first, second and third embodiments of a combined system according to the present invention. Each of the approaches work together so as to increase the efficiency of both the return distribution and return transport aspects of the network and allow the combined exemplary system to have thirty-two 5-42 MHz return bands on a single fiber. The main difference between the embodiments, as will be clear from the description below, is the location of the ITU grid transmitters and the location of the frequency stacking system (the network architecture of Figure 7 has the DWDM transmitters at the primary/secondary headend, Figure 8 has the DWDM transmitters at

the node and Figure 9 has both the frequency stacking system and the DWDM transmitters at the primary/secondary headend).

In the first embodiment of Figure 7, ITU grid DWDM transmitters 750 are located at the primary/secondary headend. As illustrated, this configuration upconverts the return path signals, with upconverter 766, at the node location (collectively the nodes are 760). Transmitted back to the primary/secondary headend via the optical distribution network they are received by the forward path block conversion receiver (BCR) 735.

Unlike a standard FSS network, which then forwards the RF output from the receiver to a downcoverter, in the first embodiment of the invention, the RF output is routed to a DWDM transmitter 750 which has an output wavelength on the ITU grid. The specific embodiment shown in Figure 7 has a concentration of four discrete 5-42 MHz passbands on each of these transmitters (of course, those skilled in the art will appreciate that the number of passbands on each of the transmitters can be greater than the illustrative "4" passbands shown and in fact, is limited based only on how much the laser can handle).

Using 200 GHz spacing, for example, the configuration of Figure 7 can optically multiplex (multiplexer 760) eight of the transmitters 750, each with its own different ITU grid wavelength, on a single fiber, providing 32 discrete 5-42 MHz passbands (1.12 GHz) on the single fiber, thereby clearly illustrating how the combination of FSS and DWDM significantly increases the reverse path traffic capacity. The signals are then routed to the headend (note that depending on the distances involved, and requirements such as redundancy, optical amplifiers may be required to meet the input requirements of the headend receivers).

At the headend the optical signals are demultiplexed by demultiplexer 770 (in the exemplary demultiplexer shown, into the eight wavelengths). Individual wavelengths are routed to receivers (one for each wavelength) BCRs 780 which are the same type as those used to receive the frequency-stacked multiplex at the primary/secondary headend. At this point the FSS system may be completed by routing the composite RF signals from the BCRs 780 to downconverters 790. The four, 5-42 MHz, RF outputs from the downconverter 790 correspond to the four coaxial legs

coming into the field node 760, and may be routed to the various return path application receivers.

It is important to note however that there is no inherent requirement to use downconversion from a communications system standpoint, but rather is dependent upon the hardware implementations. The primary/secondary or master headend receiver implementations may anticipate an RF signal in the 5-42 MHz range and may be designed to frequency convert this range of spectrum for subsequent processing, thereby requiring a downconverter component. However, implementing these receivers instead with an input bandwidth capability that encompasses the FSS spectrum would eliminate the need for the downconverter component. For example, instead of having two downconversion components before processing (one external to the receiver, and one in the receiver), a more efficient implementation could accomplish this with a single downconversion placed in the receiver, using classical CATV tuner technology in front of the demodulation function in the receiver.

In a second embodiment of the invention, illustrated by Figure 8, much of the same components as those of Figure 7 are implemented. However, as noted above, in the second embodiment DWDM transmitters are located in the node (865 collectively in Figure 8), and are driven by the stacked RF signals. Accordingly, the individual wavelengths are transmitted back to the primary/secondary headend by ITU transmitters (866 collectively).

At the primary/secondary headend, the optical signals are routed directly to multiplexers 860 (it will be appreciated that since it is possible to have different optical levels, due to different node to OTN loss budgets, some level of signal equalization may be required). The output from the multiplexer 860 is sent to the master headend in the same manner as in the first embodiment. In addition, the primary/secondary headend components of the second embodiment are assembled as those in the first embodiment as well.

One key advantage with the approach of the second embodiment is the reduced amount of active equipment located within the primary/secondary headend. As Figure 8 illustrates, it is no longer necessary to convert the optical signal back to a RF signal. Although this factor will improve performance, it places the transmitter in a more hostile environment in that temperature stability is one of the technical issues

associated with not only the technology combination described herein, but with DWDM itself.

Turning to a third embodiment of the invention, Figure 9 illustrates a primary/secondary headend-based frequency stacking and DWDM system implementation. As shown, both the frequency stacking system (shown as a 4 or 8 band system, the details of which have been discussed earlier herein) 900, and the DWDM lasers 910a-d/DWDM multiplexer 920, are all located within the primary/secondary headend. The outputs of the fiber nodes are received at the primary/secondary headend by dual receiver RPR/2 930.

Similarly, a slightly modified version of the third embodiment may also be implemented. Referring back to the network architecture shown in Figure 2, at the secondary (or primary) hub, as in the third embodiment shown in Figure 9, the reverse path data may be aggregated to drive each DWDM laser transmitter using Frequency Stacking (FS) methods. The reverse path data transmission from each subscriber is typically one of the three basic multiple access schemes -- Code Division Multiple Access (CDMA), Frequency-Division-Multiple-Access (FDMA), Time-Division-Multiple-Access (TDMA), or any combination of these schemes. Efficient use of the reverse path link, to ensure that the increased capacity is realized, uses any combination of CDMA, FDMA, TDMA to optimize the usage of the channel, together with the combined DWDM/FS network architecture.

Accordingly, in each embodiment of the invention, the frequency stacking system significantly increases the reverse path traffic capacity. This is illustrated in Figure 10, which shows a composite RF spectrum of four upconverted return path frequency blocks (5-42 MHz). In this example, a reference pilot tone is generated above the payload multiplex in order to synthesize the four-band stack. The pilot tone is transmitted along with the upconverted signal and utilized in a block down-converter unit to synchronize the down-conversion, thus removing any frequency offset errors. The composite RF signal is then used to drive each of the DWDM reverse path laser transmitters. The DWDM laser transmitters can be either directly or externally modulated DFB laser transmitters operating in 1550-nm wavelength band. As in the previous embodiments, multiplexer 920 optically multiplexes the signals from DWDM transmitters 910a-d on a single fiber to be routed to the headend, where the optical

signal may be amplified, and is optically demultiplexed to four different optical receivers. The composite output RF signal from each optical receiver is transmitted to a block down-converter unit, which extracts the four separate 5-42 MHz bands. Again, each of the high-speed data bands can be routed to return path application receivers.

Figure 11 illustrates the combined FSS/DWDM expansion process. As shown, a single shared traditional 37 MHz segment provides 74 KHz per home (for 500 home passed node). The implementation of frequency stacking (4 band) increases the shared segment to 148 Mhz thereby increasing the return bandwidth per home to 296KHz. However, the implementation of both frequency stacking and DWDM increases the return path bandwidth segment to 32 times the return path bandwidth segment, or 1184 MHz, thereby increasing the return bandwidth per home to 2.368 MHz.

Accordingly, the architecture of the present invention provides an increased capacity in the reverse path network and is well suited to implementation into existing systems that may have fiber limitations.

Although various embodiments are specifically illustrated and described herein, it will be appreciated that modifications and variations of the present invention are covered by the above teachings and within the purview of the appended claims without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A CATV architecture providing increased capacity in the reverse path network for two-way cable communication, the architecture comprising:

a plurality of optical-to-electrical conversion nodes, and a primary/secondary headend, said primary/secondary headend interconnecting the optical-to-electrical conversion nodes and a master headend, and said nodes and said primary/secondary headend together comprising,

an upconverter for receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands;

a plurality of DWDM transmitters, each transmitter having an output on the ITU grid, said transmitters transmitting a concentration of discrete passbands; and

a DWDM multiplexer, said multiplexer receiving a signal from each of said plurality of DWDM transmitters and optically multiplexing the DWDM transmitters on a single fiber, the multiplexed signals being routed to the master headend; and the master headend comprising,

a DWDM demultiplexer for demultiplexing the received signals from said DWDM multiplexer into individual wavelengths;

a plurality of block conversion receivers (BCRs) for receiving the individual wavelengths and converting the signals into composite RF signals; and

a plurality of block downconverters (BCDs) for receiving the composite RF signals from the BCRs and converting the signals into individual RF signals,

wherein the individual RF signals output from said plurality of BCDs correspond to the plurality of coax legs at each optical-to-electrical conversion node.

2. The architecture according to claim 1, said primary/secondary headend further comprising an optical amplifier, wherein said optical amplifier amplifies the multiplexed signals output from said DWDM multiplexer before being routed to the master headend.

3. The architecture according to claim 2, wherein said optical amplifier is an EDFA.

4. The architecture according to claim 3, wherein the wavelengths that comprise the ITU grid are a set of predefined frequencies spaced at 200GHz.

5. The architecture according to claim 1, wherein Time-Division-Multiple-Access (TDMA), Frequency-Division-Multiple-Access (FDMA), Code Division Multiple Access (CDMA), or any combination thereof, are used to optimize the throughput of the transport link as defined by channel parameters.

6. A CATV architecture providing increased capacity in the reverse path network for two-way cable communication, the architecture comprising:
a plurality of optical-to-electrical conversion nodes, each node comprising:

an upconverter for receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands; and

a forward path transmitter, driven by the upconverted signals output from said upconverter, transmitting a frequency stacked multiplexed signal; and a primary/ secondary headend, interconnecting the optical-to-electrical conversion nodes and a master headend, said primary/secondary headend comprising:

a plurality of forward path block conversion receivers (BCRs) for receiving the frequency stacked multiplexed signals and converting the signals into a composite RF output;

a plurality of DWDM transmitters, each having an output on the ITU grid, each of said plurality of DWDM transmitters receiving an RF output from one of said plurality of BCRs and each transmitting a concentration of discrete passbands; and

a DWDM multiplexer, said multiplexer optically multiplexing the DWDM transmitters on a single fiber, the multiplexed signals being routed to the master headend; and the master headend comprising:

a DWDM demultiplexer for demultiplexing the received signals from said DWDM multiplexer into individual wavelengths;

a plurality of block conversion receivers (BCRs) for receiving the individual wavelengths and converting the signals into composite RF signals; and

a plurality of block downconverters (BCDs) for receiving the composite RF signals from the BCRs and converting the signals into individual RF signals,

wherein the individual RF signals output from said plurality of BCDs correspond to the plurality of coax legs at each optical-to-electrical conversion node.

7. The architecture according to claim 6, said primary/secondary headend further comprising an optical amplifier, wherein said optical amplifier amplifies the multiplexed signals output from said DWDM multiplexer before being routed to the master headend.

8. The architecture according to claim 6, wherein Time-Division-Multiple-Access (TDMA), Frequency-Division-Multiple-Access (FDMA), Code Division Multiple Access (CDMA), or any combination thereof, are used to optimize the throughput of the transport link as defined by channel parameters.

9. A CATV architecture providing increased capacity in the reverse path network for two-way cable communication, the architecture comprising:

a plurality of optical-to-electrical conversion nodes, each node having,

an upconverter for receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands; and

a DWDM transmitter, having an output on the ITU grid, said transmitter transmitting a concentration of discrete passbands; and a primary/secondary headend , interconnecting the optical-to-electrical conversion nodes and a master headend, said primary/secondary headend having,

a DWDM multiplexer, said multiplexer receiving a signal from each of said DWDM transmitters and optically multiplexing the DWDM transmitters on a single fiber, the multiplexed signals being routed to the master headend; and the master headend having,

a DWDM demultiplexer for demultiplexing the received signals from said DWDM multiplexer into individual wavelengths;

a plurality of block conversion receivers (BCRs) for receiving the individual wavelengths and converting the signals into composite RF signals; and

a plurality of block downconverters (BCDs) for receiving the composite RF signals from the BCRs and converting the signals into individual RF signals,

wherein the individual RF signals output from said plurality of BCDs correspond to the plurality of coax legs at each optical-to-electrical conversion node.

10. The architecture according to claim 9, said primary/secondary headend further comprising an optical amplifier, wherein said optical amplifier amplifies the multiplexed signals output from said DWDM multiplexer before being routed to the master headend.

11. The architecture according to claim 9, wherein Time-Division-Multiple-Access (TDMA), Frequency-Division-Multiple-Access (FDMA), Code Division Multiple Access (CDMA), or any combination thereof, are used to optimize the throughput of the transport link as defined by channel parameters.

12. A CATV architecture providing increased capacity in the reverse path network for two-way cable communication, the architecture comprising:

a plurality of optical-to-electrical conversion nodes, each node having a fiber link to a primary/secondary headend; the primary/secondary headend, said primary/secondary headend interconnecting said plurality of optical-to-electrical conversion nodes and a master headend, said primary/secondary headend comprising,

an upconverter for receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands; and

a DWDM transmitter, having an output on the ITU grid, said transmitter transmitting a concentration of discrete passbands; and

a DWDM multiplexer, said multiplexer receiving a signal from each of said DWDM transmitters and optically multiplexing the DWDM transmitters on a single fiber, the multiplexed signals being routed to the master headend; and

the master headend comprising,

a DWDM demultiplexer for demultiplexing the received signals from said DWDM multiplexer into individual wavelengths;

a plurality of block conversion receivers (BCRs) for receiving the individual wavelengths and converting the signals into composite RF signals; and

a plurality of block downconverters (BCDs) for receiving the composite RF signals from the BCRs and converting the signals into individual RF signals,

wherein the individual RF signals output from said plurality of BCDs correspond to the plurality of coax legs at each optical-to-electrical conversion node.

13. The architecture according to claim 12, said primary/secondary headend further comprising an optical amplifier, wherein said optical amplifier amplifies the multiplexed signals output from said DWDM multiplexer before being routed to the master headend.

14. A method for increasing capacity in the reverse path of a two-way cable communication architecture, the architecture having a plurality of optical-to-electrical conversion nodes, a master headend, and a primary/secondary headend interconnecting the nodes and the master headend, the method comprising the steps of:

receiving a plurality of RF reverse path passbands from a plurality of coax legs and upconverting the return passbands to different passbands;

transmitting a concentration of discrete passbands using a plurality of DWDM transmitters, each transmitter having an output on the ITU grid;

optically multiplexing the signals received from the DWDM transmitters, using a DWDM multiplexer, on a single fiber;

routing the multiplexed signals to the master headend;

demultiplexing the received signals into individual wavelengths;

receiving the individual wavelengths and converting the signals into composite RF signals; and

receiving the composite RF signals and converting the signals into individual RF signals.

15. The method according to claim 14, further comprising the step of optically amplifying the multiplexed signal output from the DWDM multiplexer prior to routing the multiplexed signals to the master headend.

16. The method according to claim 14, wherein Time-Division-Multiple-Access (TDMA), Frequency-Division-Multiple-Access (FDMA), Code Division Multiple Access (CDMA), or any combination thereof, are used to optimize the throughput of the transport link as defined by channel parameters.

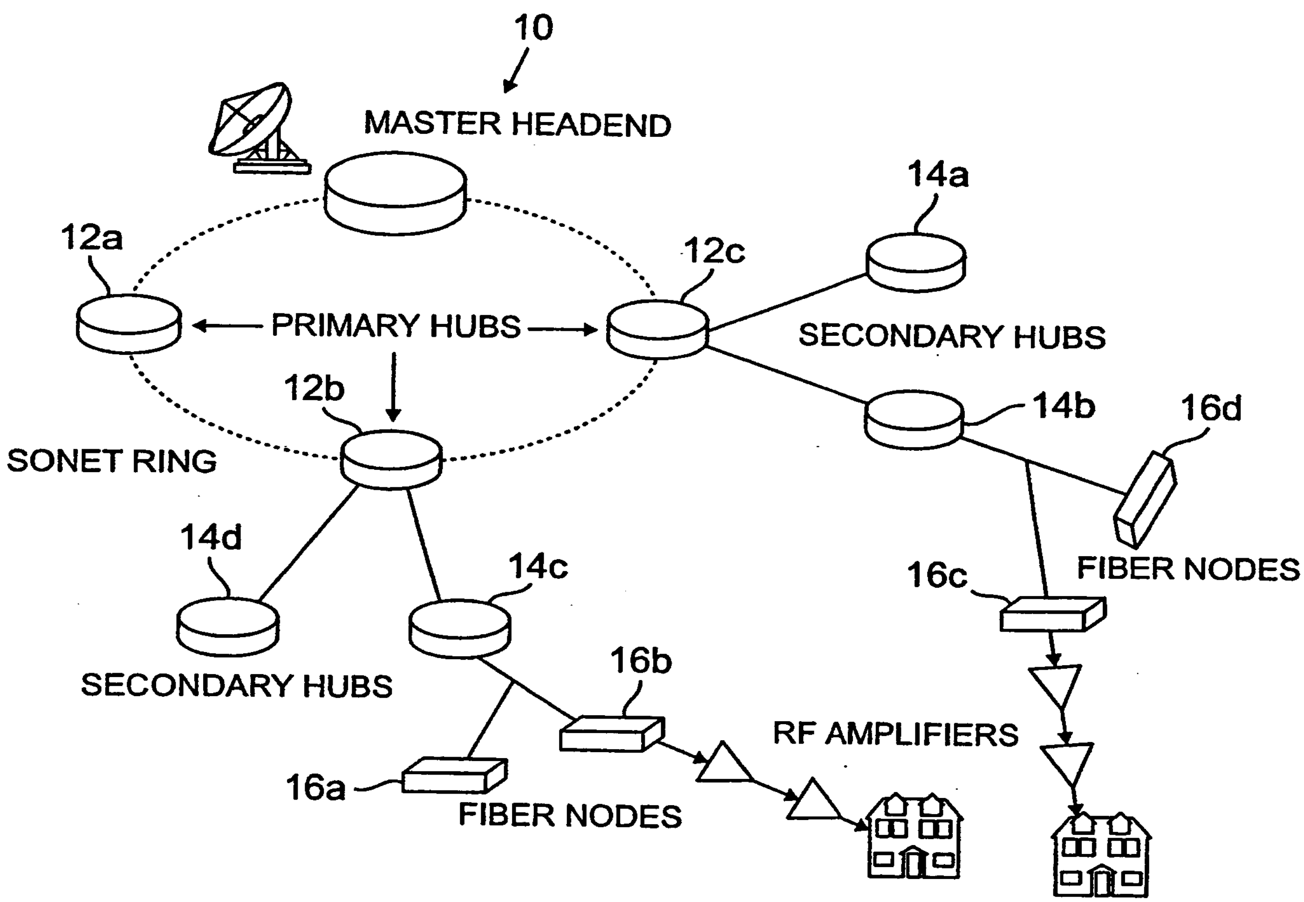

10
MASTER HEADEND
14a
12a
12c
PRIMARY HUBS
SECONDARY HUBS
12b
14b
16d
SONET RING
14d
14c
16c
FIBER NODES
SECONDARY HUBS
16b
RF AMPLIFIERS
16a
FIBER NODES

FIG. 1

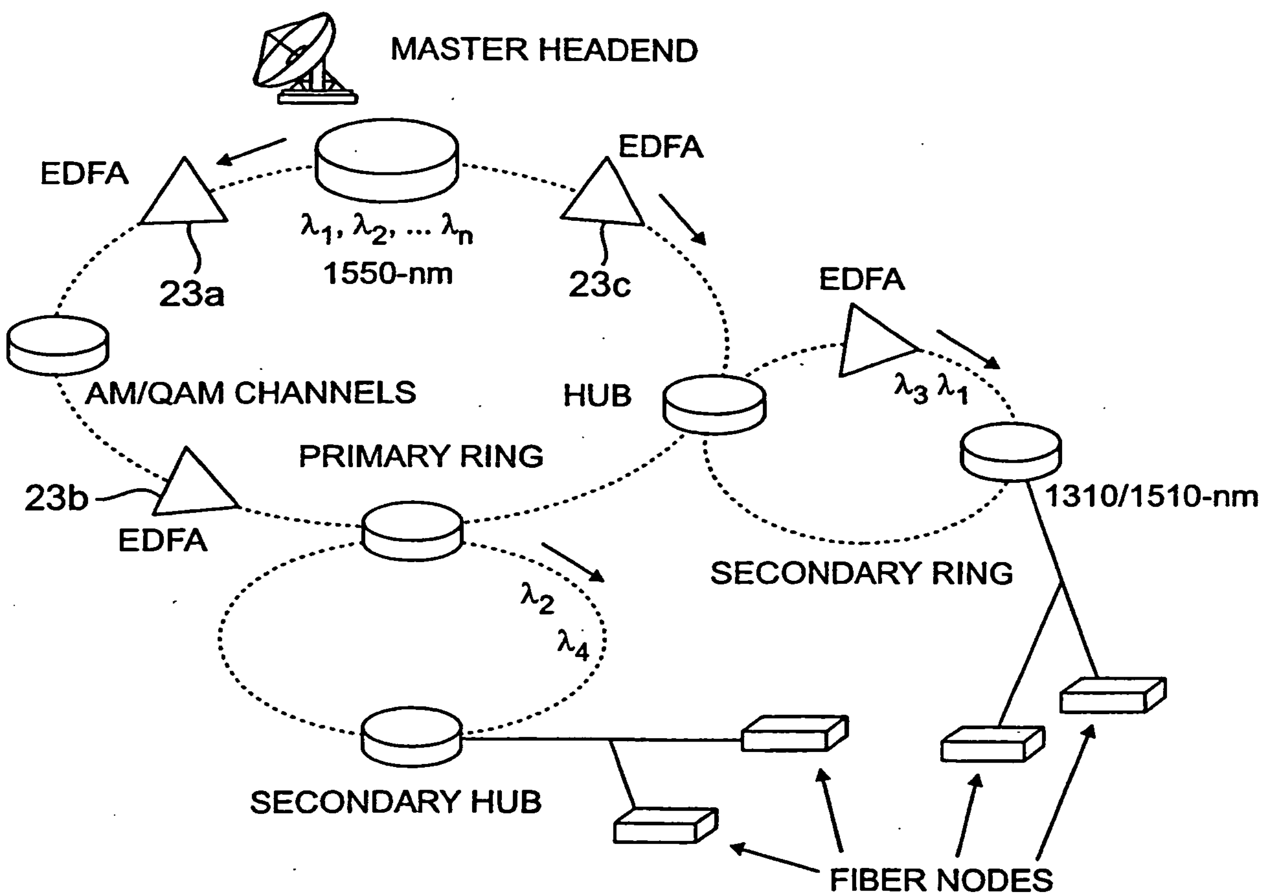

MASTER HEADEND
EDFA
EDFA
$\lambda_1, \lambda_2, \ldots \lambda_n$
1550-nm
23a
23c
EDFA
AM/QAM CHANNELS
HUB
$\lambda_3 \lambda_1$
PRIMARY RING
23b
EDFA
1310/1510-nm
SECONDARY RING
λ_2
λ_4
SECONDARY HUB
FIBER NODES

FIG. 2

3/11

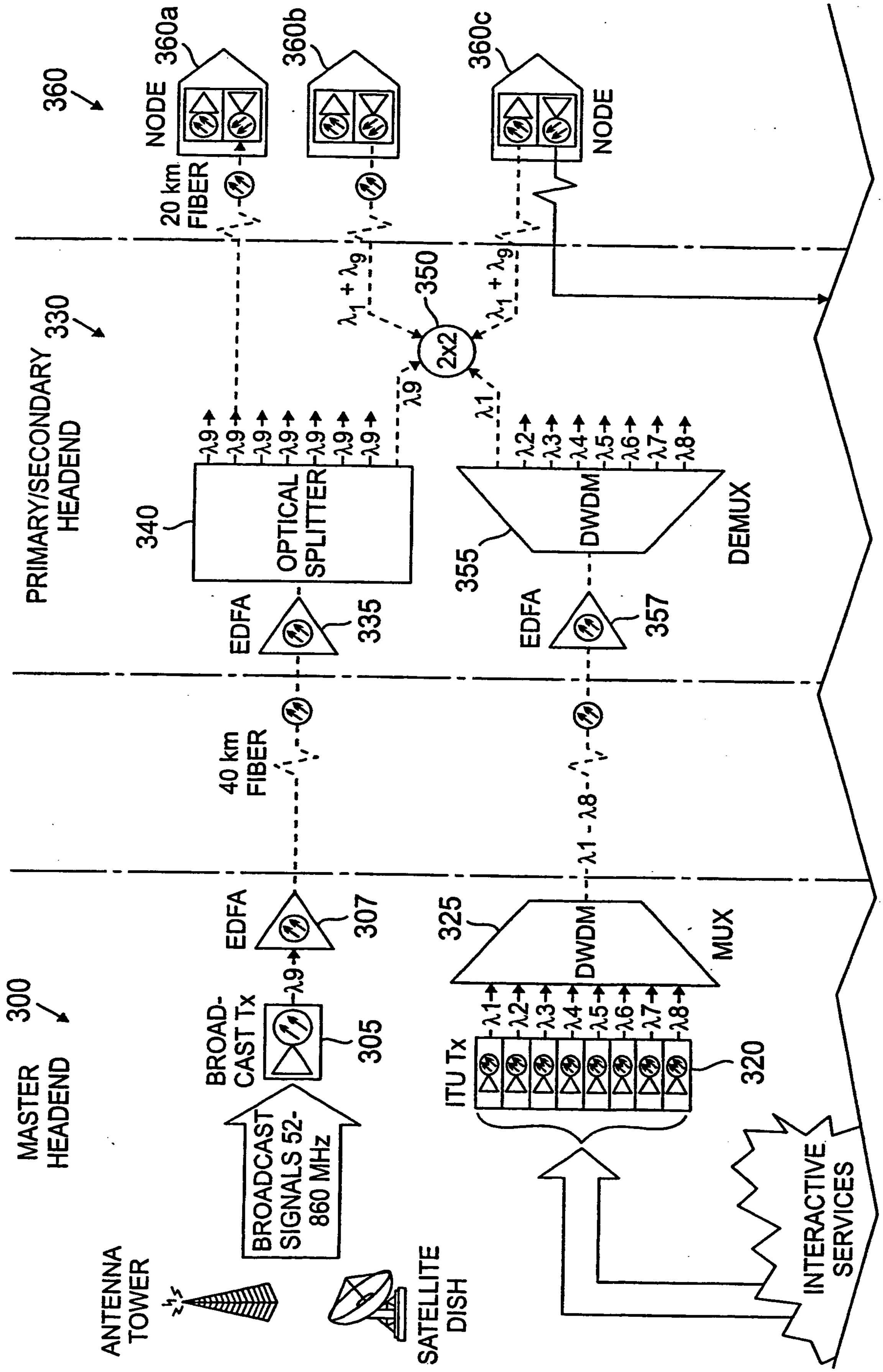


FIG. 3A
PRIOR ART

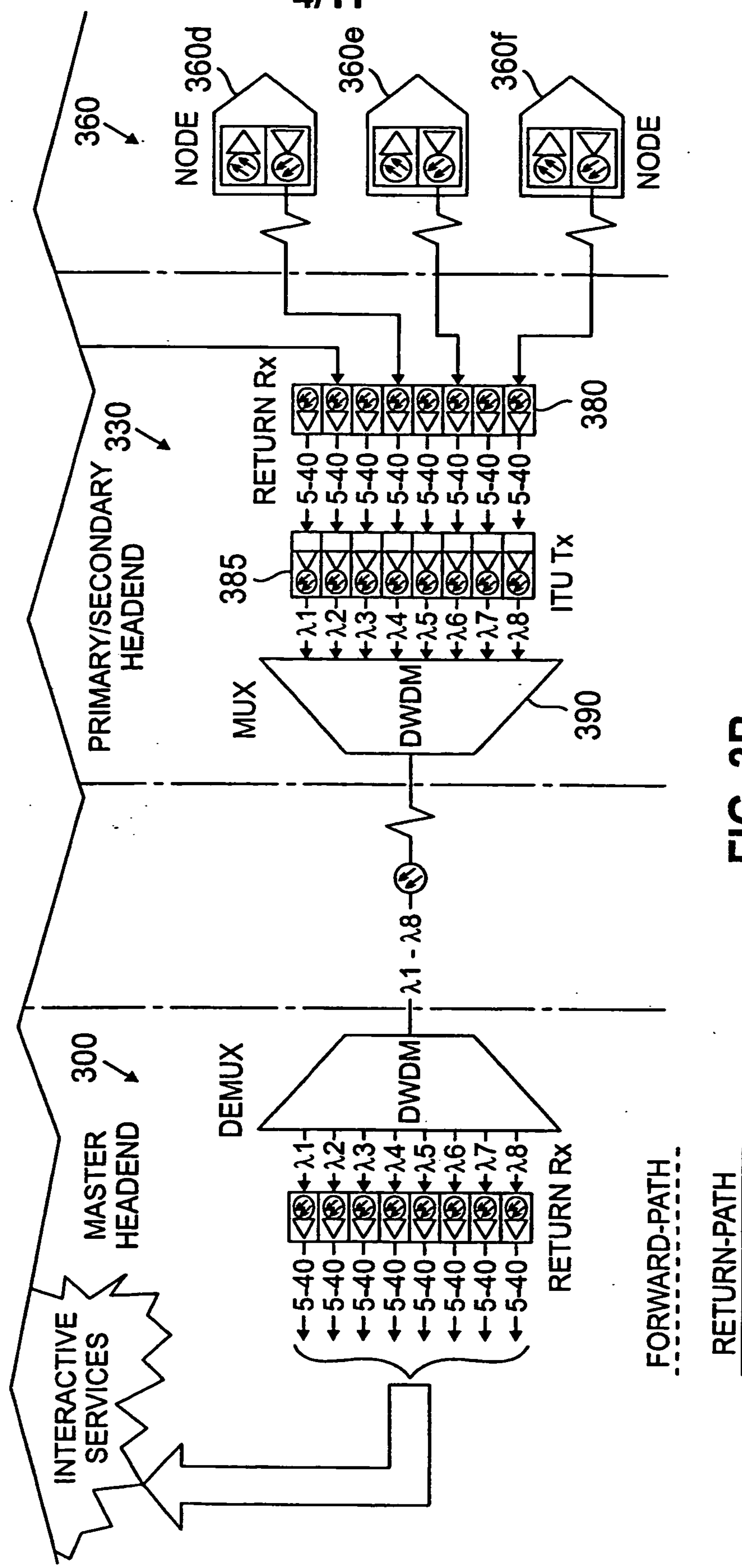


FIG. 3B
PRIOR ART

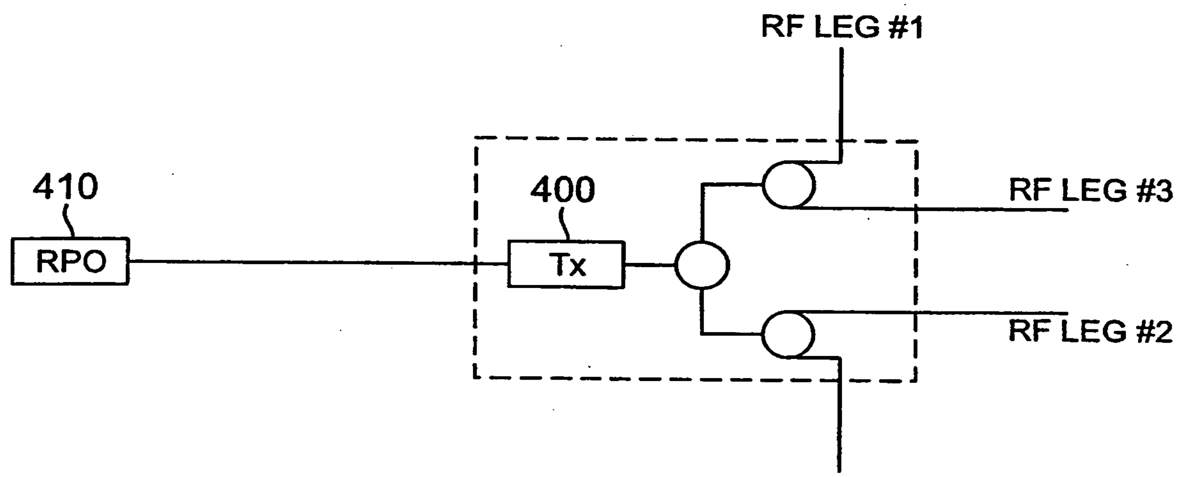

RF LEG #1
410
RPO
400
Tx
RF LEG #3
RF LEG #2

FIG. 4

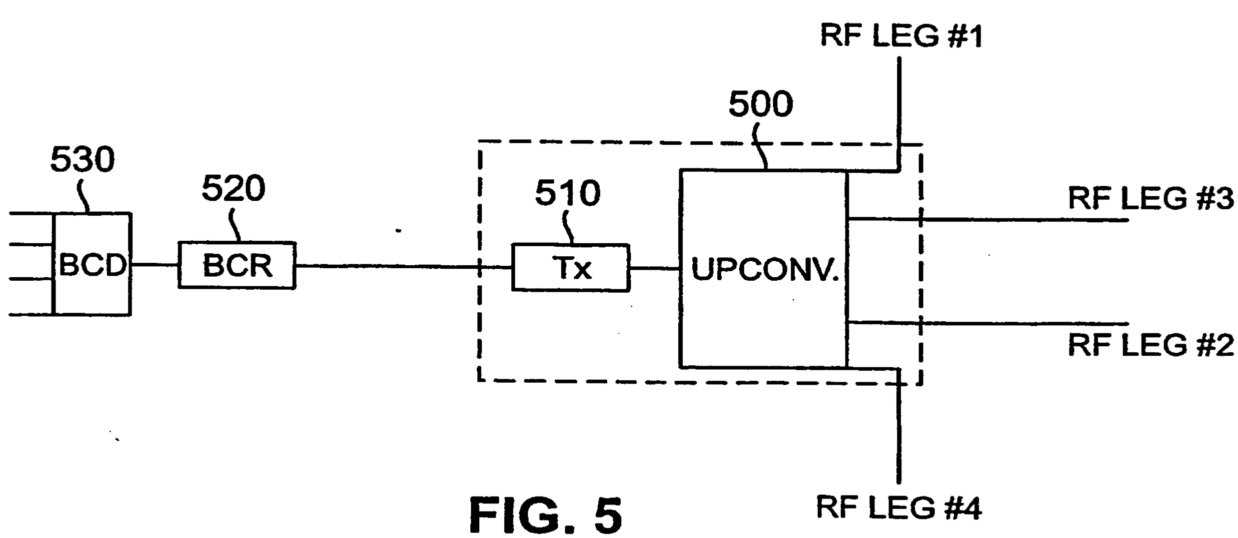

RF LEG #1
500
530
520
510
BCD
BCR
Tx
UPCONV.
RF LEG #3
RF LEG #2
RF LEG #4

FIG. 5

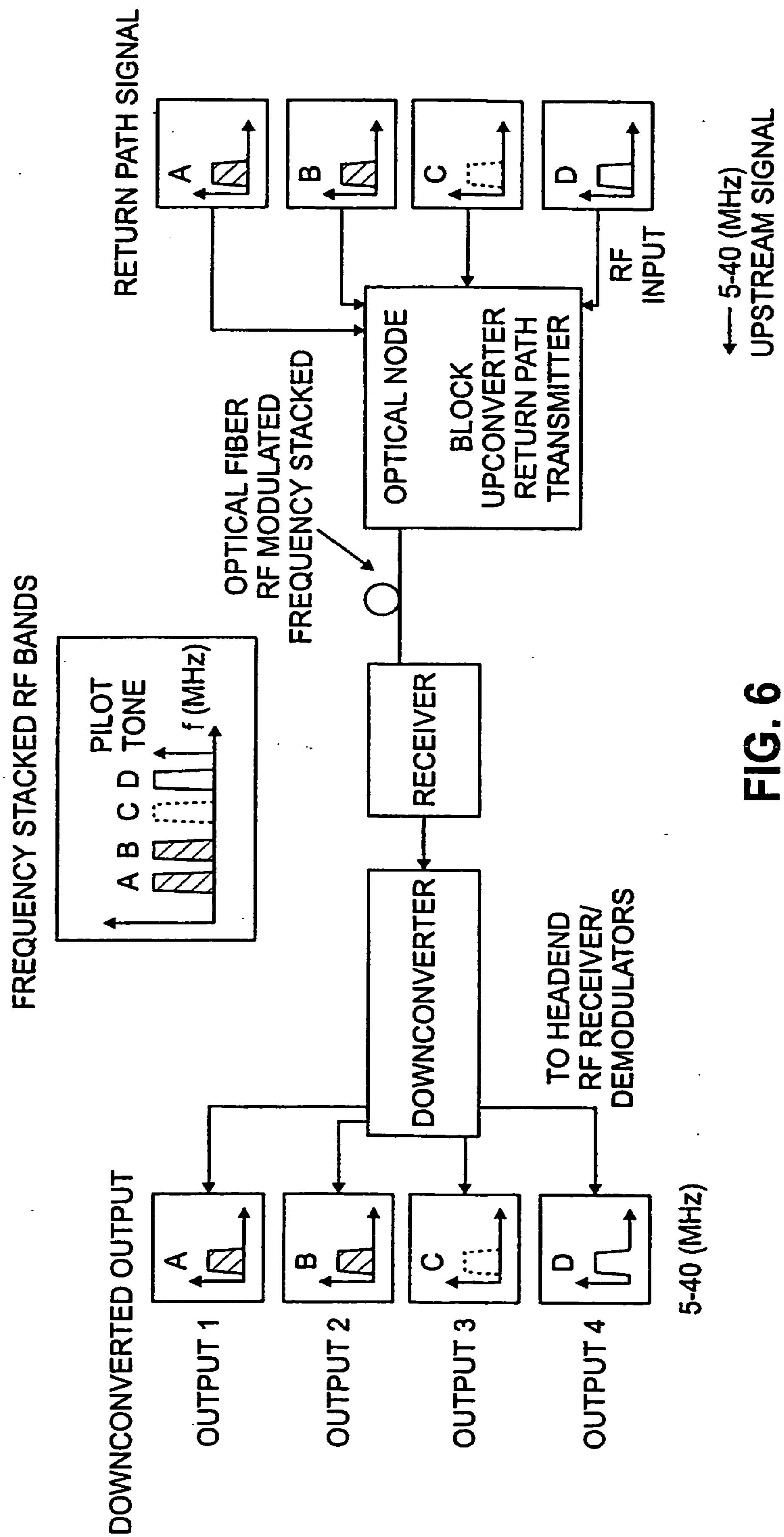
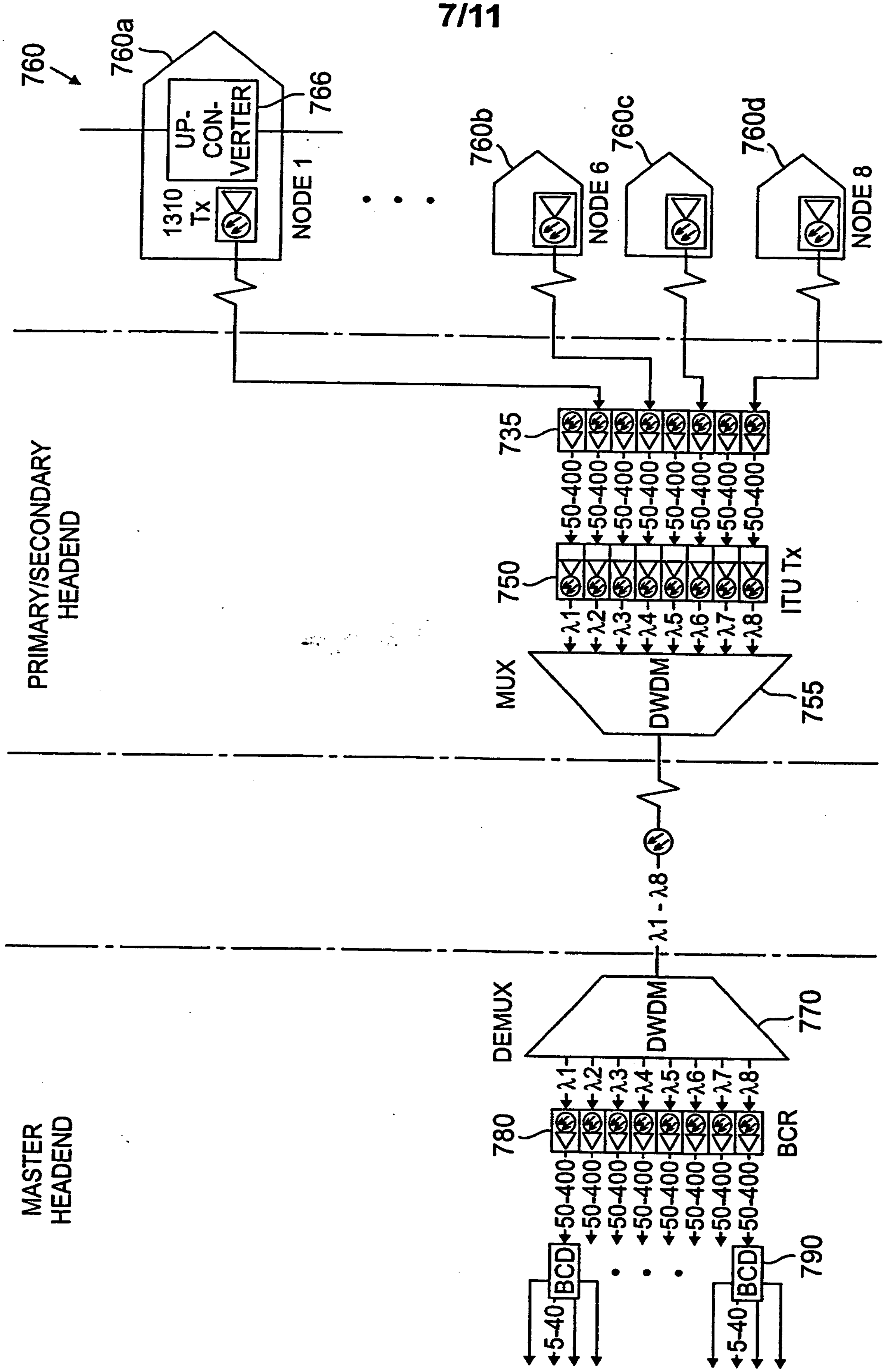
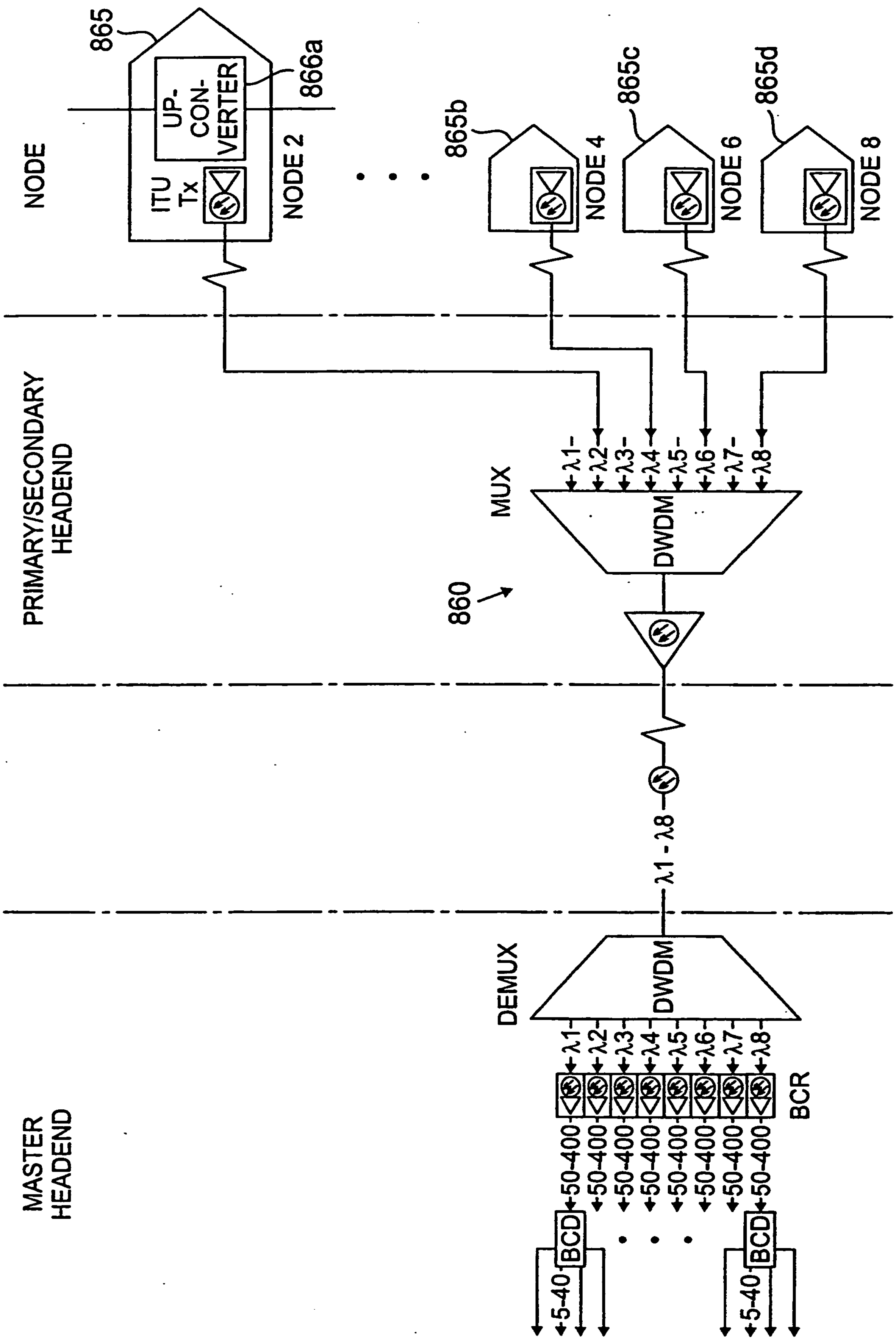

RETURN PATH SIGNAL
A
B
C
D
RF INPUT
5-40 (MHz) UPSTREAM SIGNAL
OPTICAL NODE
BLOCK UPCONVERTER RETURN PATH TRANSMITTER
OPTICAL FIBER RF MODULATED FREQUENCY STACKED
FREQUENCY STACKED RF BANDS
A B C D
PILOT TONE
f (MHz)
RECEIVER
DOWNCONVERTER
TO HEADEND RF RECEIVER/ DEMODULATORS
DOWNCONVERTED OUTPUT
OUTPUT 1
OUTPUT 2
OUTPUT 3
OUTPUT 4
5-40 (MHz)

FIG. 6



DWDM/FSS CONFIGURATION 1

FIG. 7



DWDM/FSS CONFIGURATION 2

FIG. 8

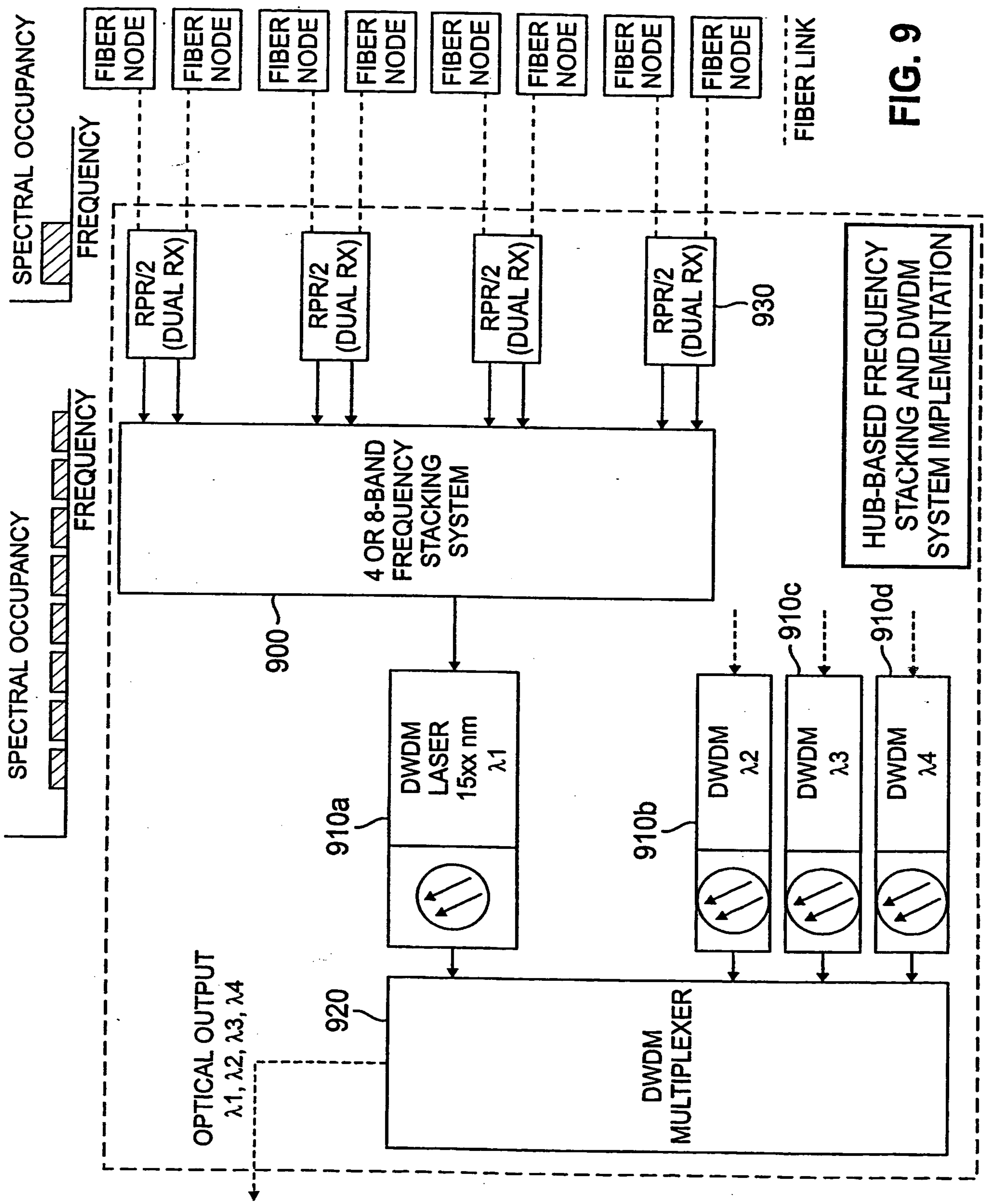

SPECTRAL OCCUPANCY
FREQUENCY
FIBER NODE
FIBER NODE
FIBER NODE
FIBER NODE
FIBER NODE
FIBER NODE
FIBER NODE
FIBER NODE
FIBER LINK
RPR/2 (DUAL RX)
RPR/2 (DUAL RX)
RPR/2 (DUAL RX)
RPR/2 (DUAL RX)
930
HUB-BASED FREQUENCY STACKING AND DWDM SYSTEM IMPLEMENTATION
SPECTRAL OCCUPANCY
FREQUENCY
4 OR 8-BAND FREQUENCY STACKING SYSTEM
900
910a
DWDM LASER 15xx nm λ1
910b
DWDM λ2
910c
DWDM λ3
910d
DWDM λ4
920
DWDM MULTIPLEXER
OPTICAL OUTPUT λ1, λ2, λ3, λ4

FIG. 9

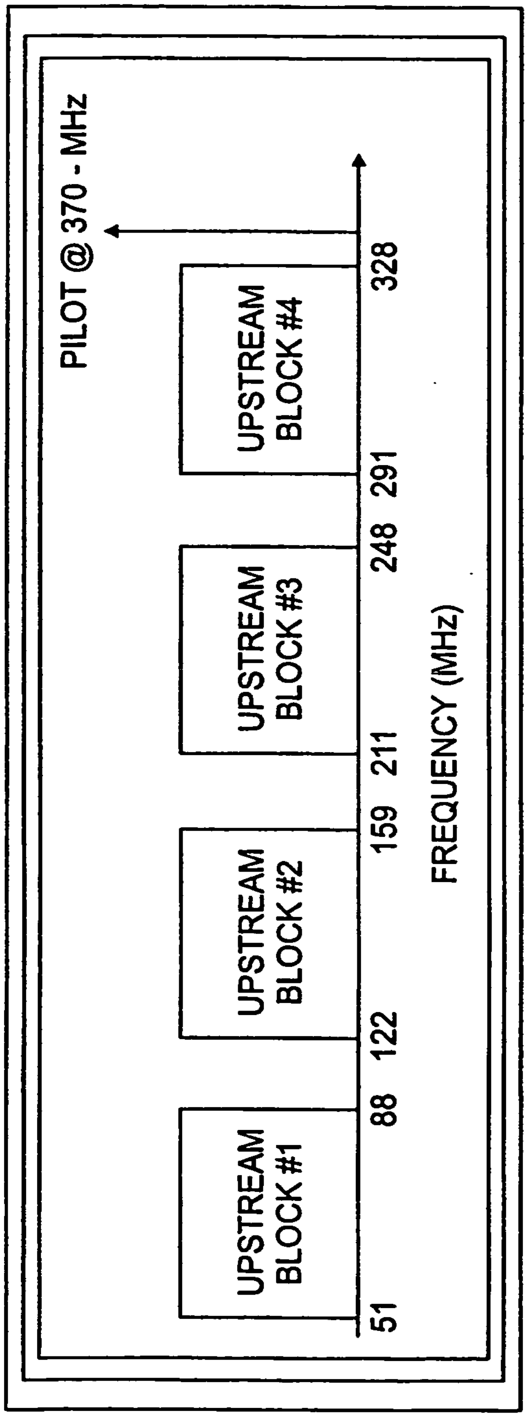

PILOT @ 370 - MHz
UPSTREAM BLOCK #1
UPSTREAM BLOCK #2
UPSTREAM BLOCK #3
UPSTREAM BLOCK #4
51
88
122
159
211
248
291
328
FREQUENCY (MHz)

FIG. 10

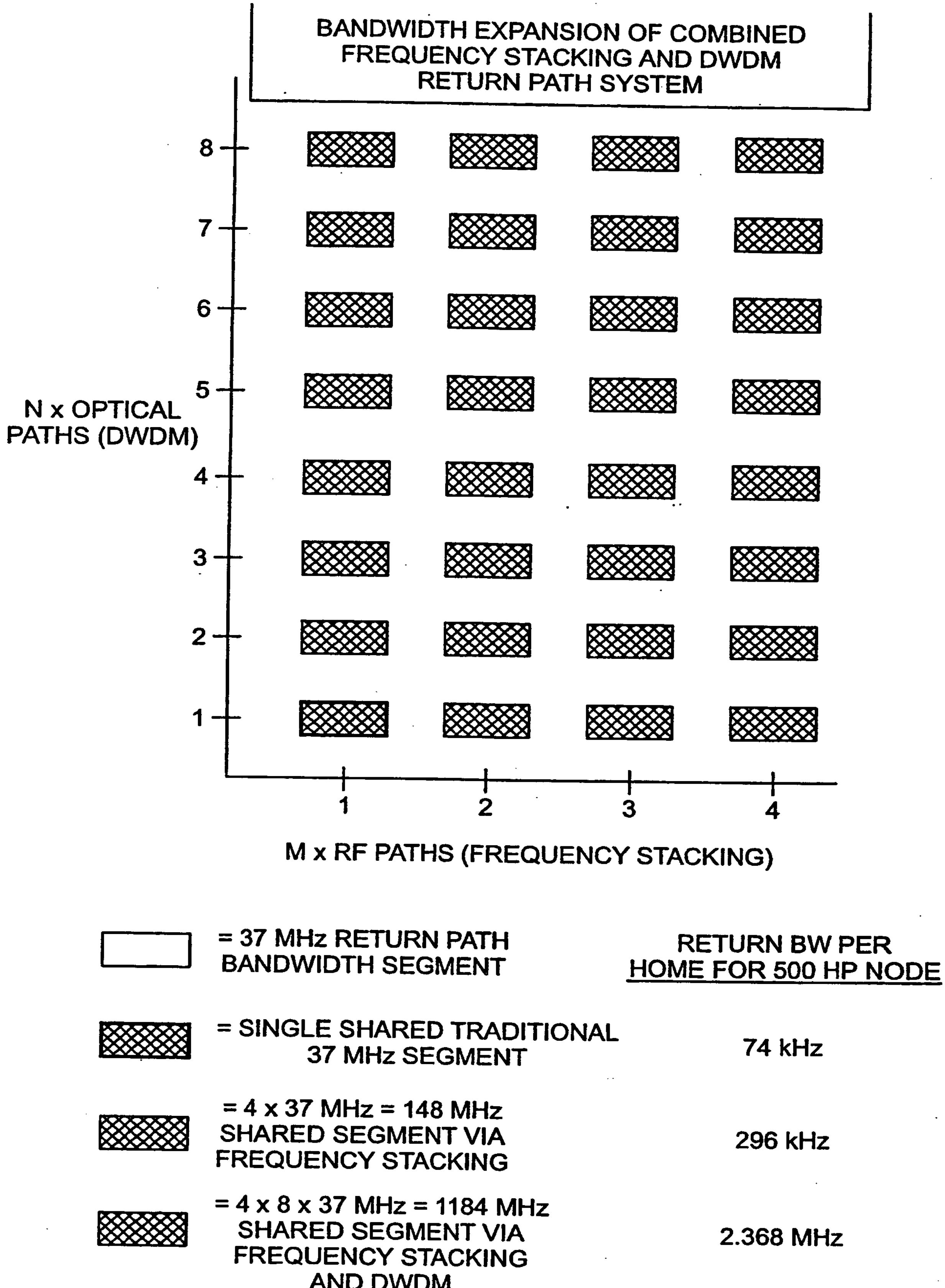

BANDWIDTH EXPANSION OF COMBINED FREQUENCY STACKING AND DWDM RETURN PATH SYSTEM
8
7
6
5
4
3
2
1
N x OPTICAL PATHS (DWDM)
1
2
3
4
M x RF PATHS (FREQUENCY STACKING)
= 37 MHz RETURN PATH BANDWIDTH SEGMENT
RETURN BW PER HOME FOR 500 HP NODE
= SINGLE SHARED TRADITIONAL 37 MHz SEGMENT
74 kHz
= 4 x 37 MHz = 148 MHz SHARED SEGMENT VIA FREQUENCY STACKING
296 kHz
= 4 x 8 x 37 MHz = 1184 MHz SHARED SEGMENT VIA FREQUENCY STACKING AND DWDM
2.368 MHz

FIG. 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/10358

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04J14/02 H04N7/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N H04J H04H H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 49248 A (FIBER OPTIC NETWORK SYSTEMS CO) 24 December 1997 (1997-12-24)	1-4,6,7, 9,10, 12-15
Y	page 1, line 3-13 page 19, line 3-33 page 31, line 1-20 page 32, line 1-27 page 33, line 10-21 ---	5,8,11, 16
Y	US 5 809 395 A (HART GEORGE MAYNARD ET AL) 15 September 1998 (1998-09-15) column 1, line 10-17 column 3, line 26-37 column 4, line 40-50 column 9, line 36-60 column 23, line 55-67 ---	5,8,11, 16
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 August 2000	08/08/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Authorized officer Traverso, A

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/10358

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 136 411 A (PAIK WOO H ET AL) 4 August 1992 (1992-08-04) column 1, line 12-15 column 2, line 8-43 column 4, line 3-24 column 5, line 29-56 column 8, line 65 -column 9, line 26 ---	1-16
A	US 5 699 176 A (COHEN LEONARD G) 16 December 1997 (1997-12-16) column 1, line 4-8 column 4, line 7-27 column 4, line 46-67 column 5, line 55 -column 6, line 35 ---	3
A	US 4 064 460 A (GARGINI ERIC JOHN WEST) 20 December 1977 (1977-12-20) column 1, line 10-29 column 2, line 18-38 column 3, line 44 -column 4, line 18 -----	6

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/10358

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9749248	A	24-12-1997	US	5953139	A	14-09-1999
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			CA	2059370	A,C	16-07-1992
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			US	5802173	A	01-09-1998
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			AU	6254690	A	23-05-1991
			CA	2025521	A,C	20-03-1991
			DE	69024006	D	18-01-1996
			DE	69024006	T	15-05-1996
			DK	419137	T	29-04-1996
			EP	0419137	A	27-03-1991
			FI	98030	B	13-12-1996
			JP	3167987	A	19-07-1991
			KR	9406733	B	27-07-1994
			NO	179889	B	23-09-1996
			NZ	235309	A	23-12-1992
			AU	2668088	A	15-06-1989
			DK	687588	A	12-06-1989
			EP	0320181	A	14-06-1989
			JP	2002796	A	08-01-1990
			NO	885496	A	12-06-1989
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US 4064460	A	20-12-1977	GB	1480749	A	20-07-1977
			BE	826763	A	16-07-1975
			CA	1052446	A	10-04-1979
			CH	589981	A	29-07-1977
			DE	2510865	A	18-09-1975
			ES	435664	A	01-12-1976
			FR	2264447	A	10-10-1975
			IL	46827	A	31-07-1977
			IT	1032322	B	30-05-1979
			JP	50133701	A	23-10-1975
			NL	7503107	A,B	18-09-1975
			SE	407002	B	05-03-1979
			SE	7502806	A	17-09-1975
			ZA	7501615	A	25-02-1976